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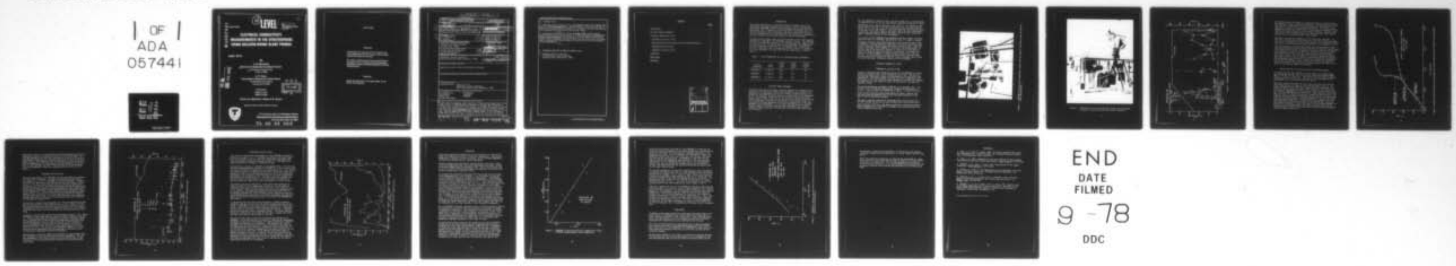

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ELECTRICAL CONDUCTIVITY MEASUREMENTS IN THE STRATOSPHERE USING BALLOON-BORNE BLUNT PROBES

JUNE 1978

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Blunt probes for measuring polar electrical conductivity have been flown on the recent series of STRATCOM balloon experiments. Although the instrument has primarily been employed with rocket systems, it has been found useful for studying ionization processes in the stratosphere when flown on balloon platforms. The three most recent ~~STRATCOM~~ balloon flights, launched from Holloman Air Force Base, New Mexico, floated in different altitude regions of the stratosphere. These made possible the study of conductivity and its associated variability

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20. ABSTRACT (cont)

at relatively fixed altitudes of 48 km ~~(18 September 1972)~~, 28 km ~~(22 May 1974)~~, and 39 km ~~(23-25 September 1975)~~. Another function of the blunt probe was to measure the ionization effects caused by an ultraviolet lamp which was operated for designated time periods during the balloon flights.

In conjunction with the 28 km balloon flight ~~on 22 May 1974~~, a rocket-launched parachute-borne blunt probe experiment was conducted ~~from~~ nearby, ~~White Sands Missile Range, New Mexico~~, thus providing an altitude profile for electrical conductivity to supplement the data obtained from the balloon-borne instrument. General agreement was observed between the rocket data and the corresponding balloon measurements.

9. PERFORMING ORGANIZATION NAME AND ADDRESS (cont)

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CONTENTS

INTRODUCTION

Blunt probe experiments for measuring electrical conductivity in the stratosphere have been conducted on the recent series of stratospheric composition (STRATCOM) balloon flights launched from Holloman Air Force Base (HAFB), NM. In addition to providing useful information about ionization processes in the stratosphere, the blunt probe electrical conductivity measurements have been observed to be influenced by temperature, sunrise conditions, and vertical motions of the balloon package.

The three balloon flights which will be discussed in this report are the STRATCOM III, STRATCOM V, and STRATCOM VI balloon flights. The STRATCOM III balloon package was launched on 18 September 1972 and reached a float altitude of 48 km. The launch dates for the STRATCOM V and STRATCOM VI balloon flights were 22 May 1974 and 23 September 1975, respectively; and their respective float altitudes were 28 km and 39 km. A summary of the flight parameters for these three balloon experiments is given in Table 1.

TABLE 1. FLIGHT PARAMETERS FOR THE STRATCOM BALLOON EXPERIMENTS

Balloon Experiment	Launch Date	Launch Time (MST)	Flight Period (hours)	Float Altitude (km)
STRATCOM III	18 Sep 72	0304	≈ 6	48
STRATCOM V	22 May 74	0122	≈ 24	28
STRATCOM VI	23 Sep 75	2257	≈ 34	39

THE BLUNT PROBE EXPERIMENT

The blunt probe uses a flat plate collector geometry for charged particle collection. By applying a known voltage waveform to the collector and measuring the corresponding current of collected charged particles, it is possible to determine the polar electrical conductivity of the atmosphere [1,2]. The principal launch vehicle for the blunt probe has been the meteorological rocket, which carries the payload to apogee and then ejects it on a parachute. This form of experiment is particularly useful for studying the altitude dependence of electrical conductivity in the lower mesosphere and stratosphere. In the recent STRATCOM series of balloon flights, however, the blunt probe has been found useful for studying electrical conductivity and its associated variability when flow on balloon platforms.

For the STRATCOM III balloon flight, the blunt probe (Fig. 1) was operated in conjunction with an ion mass spectrometer experiment conducted by Sandia Laboratories and a Lyman-α ionization lamp (1216 Å). The ionization lamp was located to the side of the mass spectrometer with its beam directed across the front of the aperture. The blunt probe was positioned obliquely in the path of the lamp's beam on the other side of the mass spectrometer, and thus was used both to monitor the lamp's operation and to study the lamp's ionization effects on the stratosphere.

For the more recent STRATCOM V and STRATCOM VI balloon flights, the blunt probe was flown in a different configuration (Fig. 2) in which a krypton discharge ionization lamp (1236 Å) was positioned beside the blunt probe. In addition, a Gerdien condenser experiment for measuring electrical conductivity was also located beside the krypton discharge lamp. These particular instruments were extended on a horizontal arm approximately 1 m from the rest of the scientific package to reduce stray field effects possibly induced by other instruments on the package. The probe's collector was oriented downward to avoid possible photoemission from its surface. In this particular instrument configuration, the blunt probe was also operated in conjunction with the krypton discharge lamp in order to monitor the lamp's ionization effects on the stratosphere.

ELECTRICAL CONDUCTIVITY DATA

STRATCOM III Balloon Flight

A graph of the blunt probe conductivity data for the STRATCOM III balloon flight is plotted in Fig. 3 as a function of local time. The positive and negative conductivity values are represented by plus and minus signs, respectively. The time-averaged values for electrical conductivity are also shown in the figure and have been connected by straight line segments. The upper curve in the figure is a plot of the balloon's altitude as a function of time.

The balloon package was launched at 0304 MST on 18 September 1972. The notation "0-2" at 0439 MST represents two independent measurements of σ_+ and σ_-, both of which were negligible in value. In general, the conductivity data obtained during ascent while the Lyman-α lamp was off indicated that the probe did not collect ions while operating in the wake of the rising balloon package.

The Lyman-α lamp was operated for designated time intervals while the balloon ascended and during the sunrise period while the balloon was at float altitude ($Z \approx 48$ km). The nonzero electrical conductivity measurements obtained prior to 0700 MST are thought to be associated with ionization induced by the lamp.

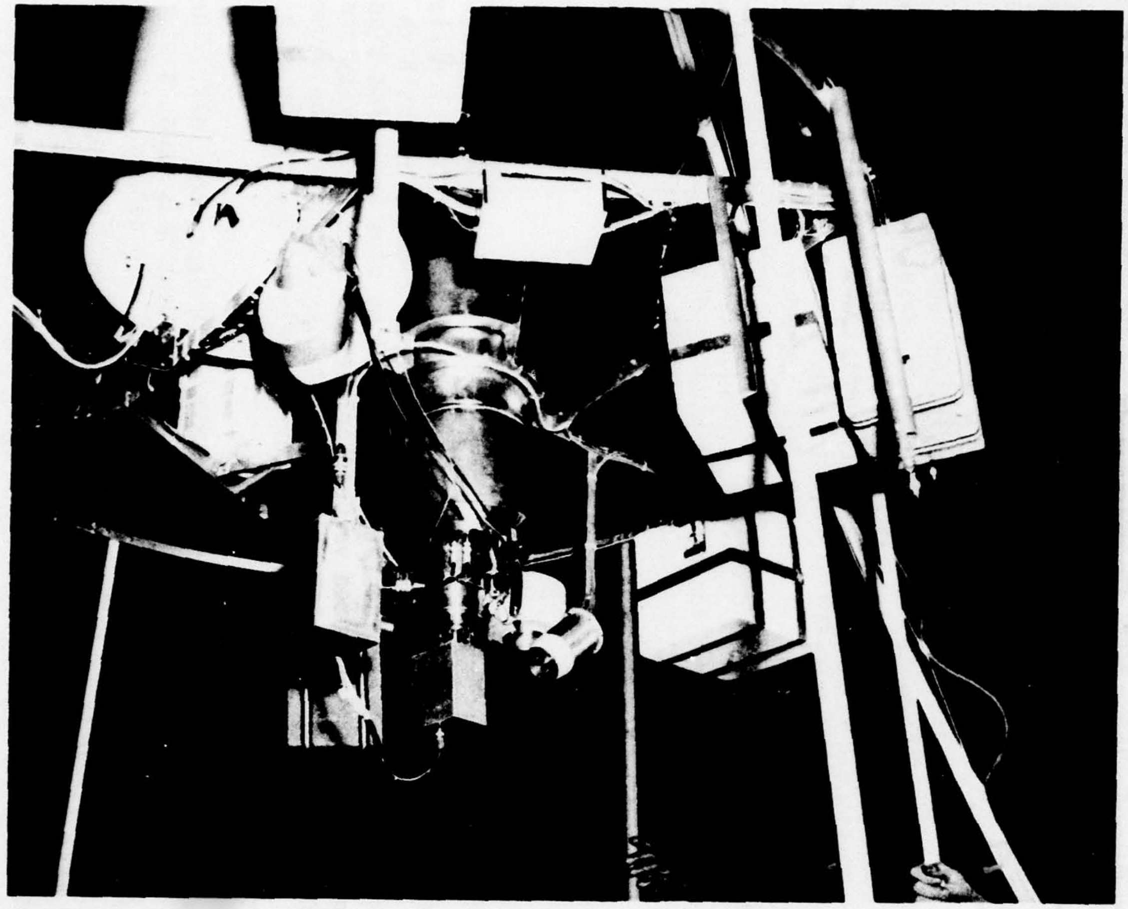

Figure 1. STRATCOM III blunt probe experiment (shown with the Lyman-α ionization lamp and the ion mass spectrometer).

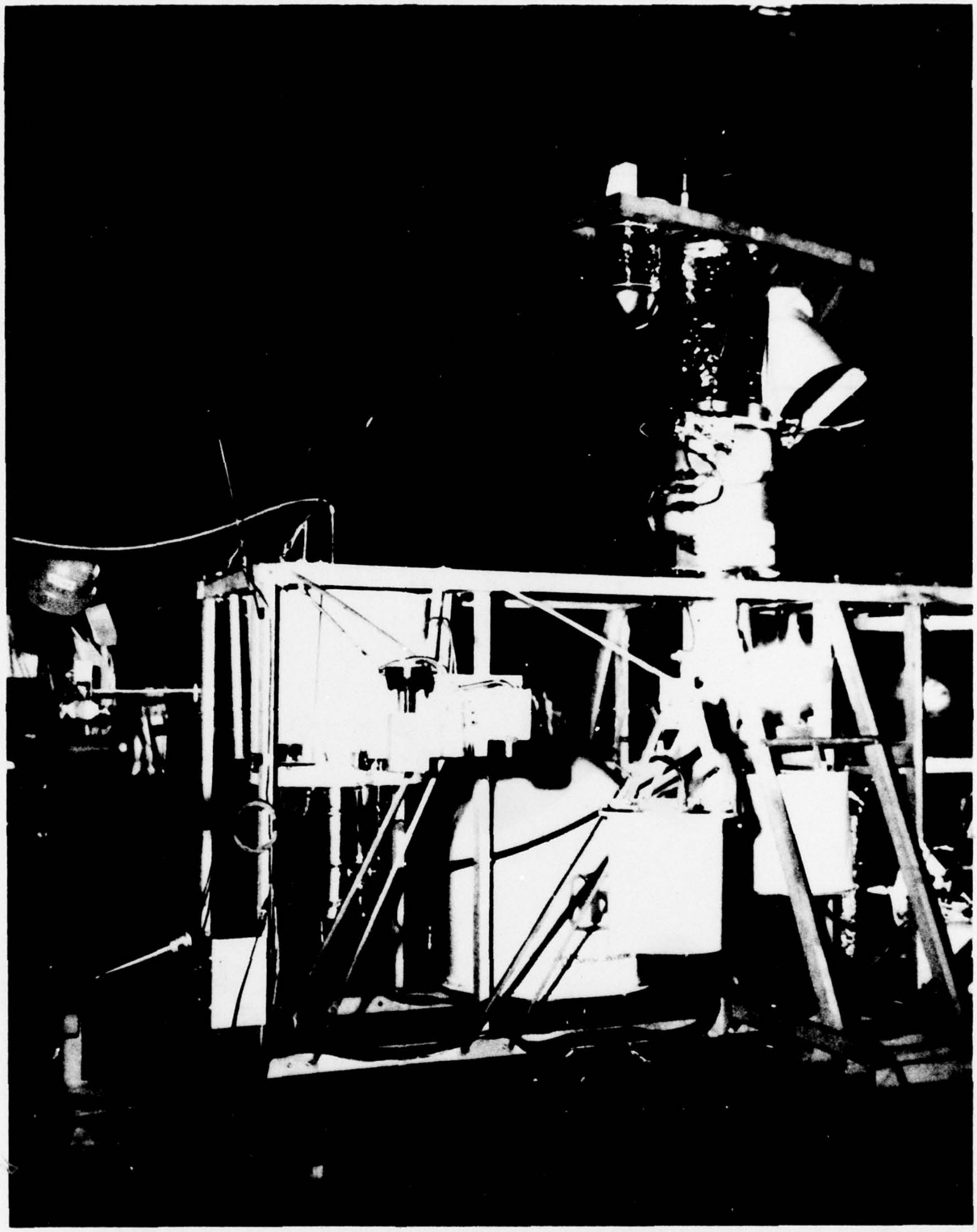

Figure 2. STRATCOM VI blunt probe experiment (shown with the krypton discharge ionization lamp and the Gerdien condenser).

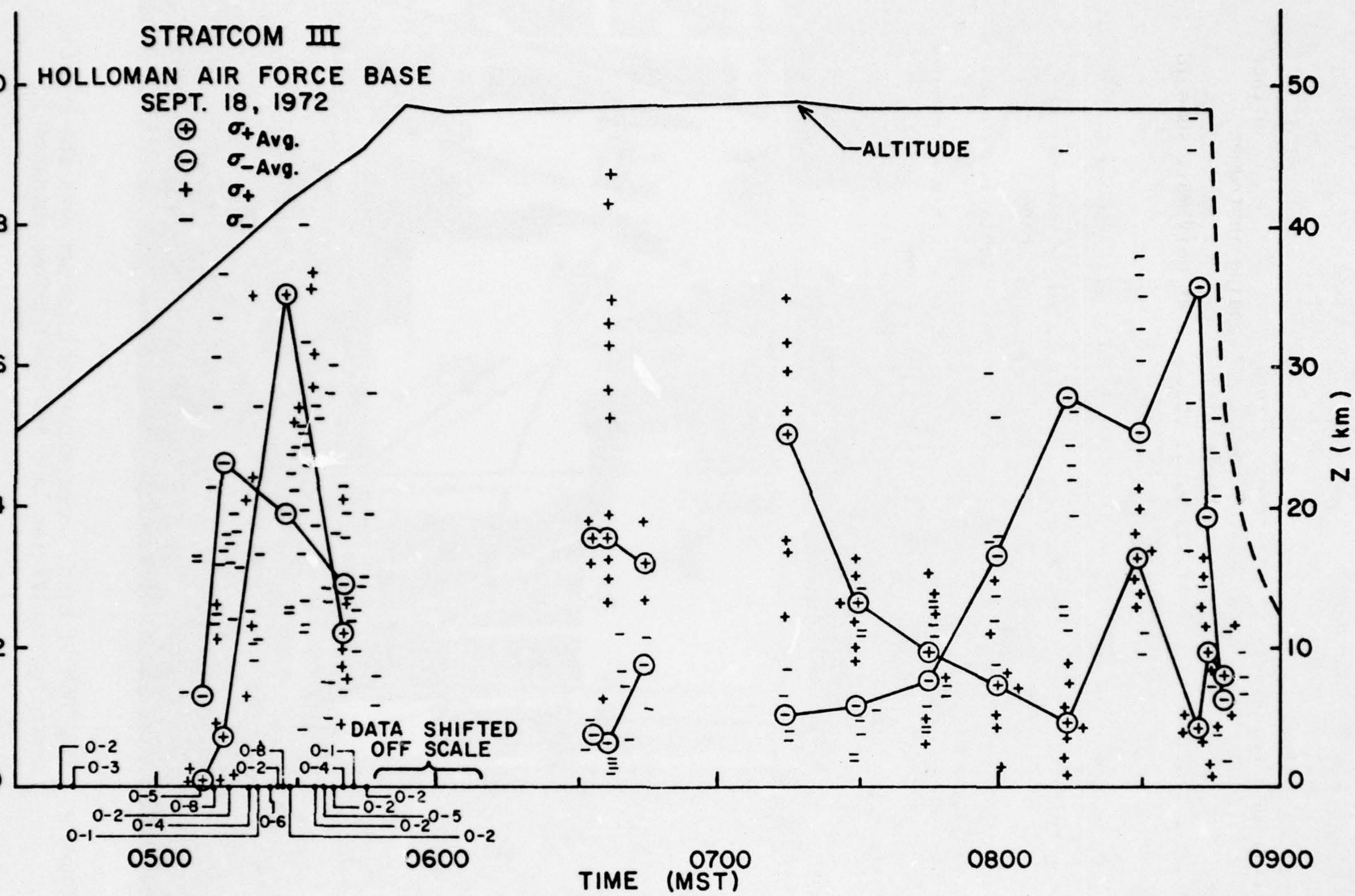

Figure 3. STRATCOM III electrical conductivity data.

At 0545 MST, which corresponds to ultraviolet sunrise, the blunt probe was observed to shift in potential resulting in the data going off scale. Such behavior is explainable by photoemission from the probe if it is operating in a relatively charge-free environment. This would further suggest the presence of a wake effect on the ascending instrument resulting from its close proximity to the scientific package. Recovery from the probe's shift in potential was first observed at 0611 MST, some 18 minutes after the balloon reached float altitude.

The Lyman-α lamp was not operated on this flight after 0700 MST. For the float altitude data obtained after this time, the positive and negative electrical conductivity values were observed to be somewhat variable. The positive conductivity values were generally in the range of 1 to 4 x 10^{-13} mho/cm and, as a whole, were smaller than representative rocket-launched parachute-borne blunt probe conductivity values for that altitude. These comparatively smaller conductivity values are possibly attributed to a reduction in positive ion mobility, resulting from the positive ions hydrating with outgassed water vapor from the balloon package to form large cluster ions. The negative electrical conductivity values, which were initially smaller than the corresponding positive conductivity measurements, were observed to build up in value until the balloon was cut down at 0845 MST. After cutdown, the positive and negative electrical conductivity measurements became comparable and fell off in value as the probe descended on a parachute.

Rocket-Launched Parachute-Borne Blunt Probe Measurements

In conjunction with the STRATCOM V balloon flight, a parachute-borne blunt probe was launched from nearby White Sands Missile Range (WSMR), NM, at 1115 MST on 22 May 1974. This particular experiment provided an altitude profile for electrical conductivity, thus supplementing the measurements from the balloon-borne blunt probe.

Electrical conductivity data from the rocket experiment were obtained from approximately 70 km down to 20 km and are shown in Fig. 4. The points represent actual conductivity measurements with smoothed curves fitted to the data points as shown. Also included in this figure are the ranges of representative float altitude positive conductivity values for the three STRATCOM balloon experiments. With respect to the rocket data, the value for negative electrical conductivity above 40 km is considerably larger than the corresponding positive electrical conductivity value for the same altitude. The steep gradient in the curve for negative electrical conductivity at approximately 45 km suggests the altitude above which electrons are present in the daytime [3]. The curve for positive electrical conductivity shows little altitude dependence in the 50 to 60 km altitude region, with a knee at approximately 65 km indicating the altitude at which ionization caused by solar ultraviolet radiation becomes significant.

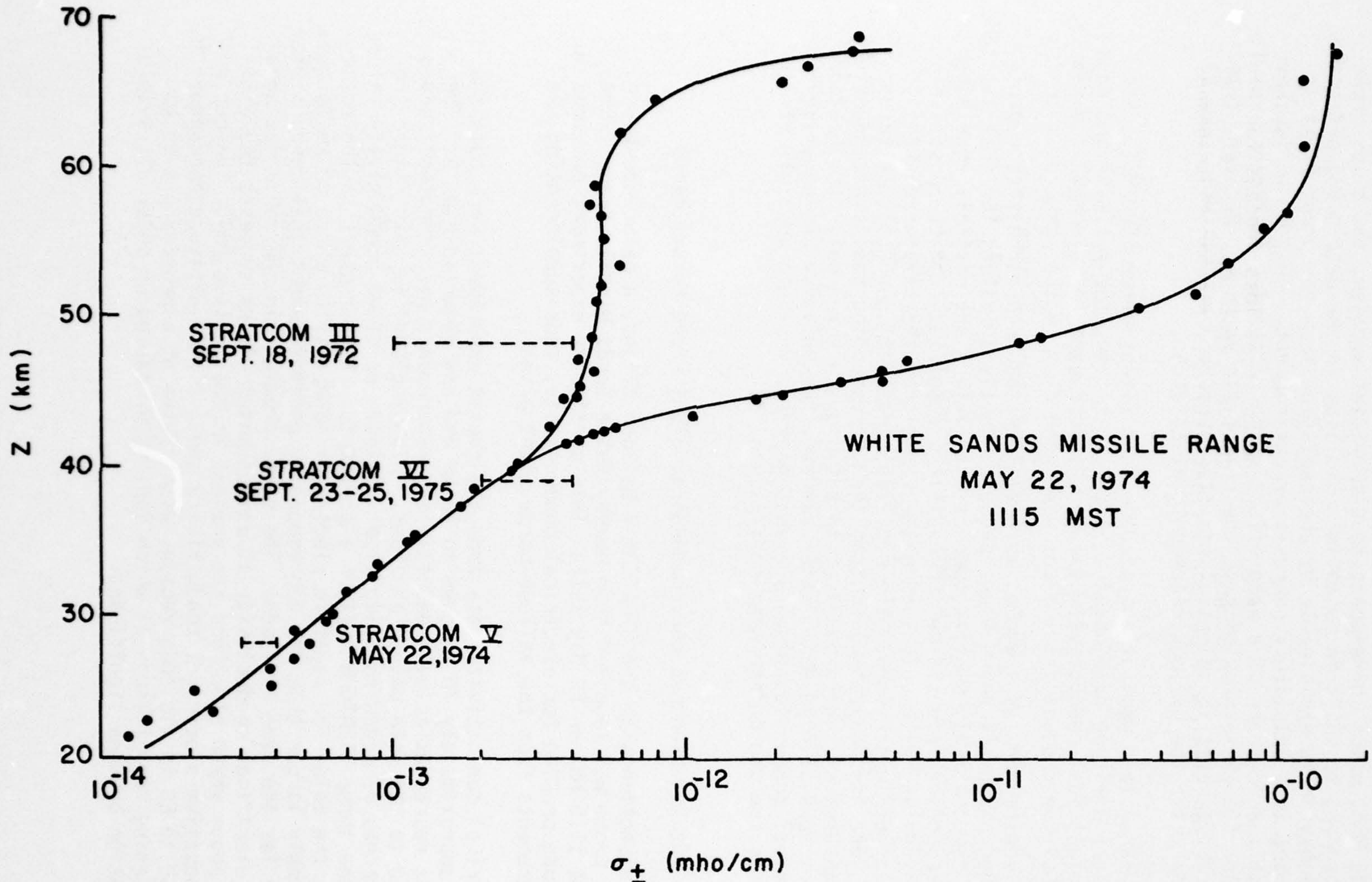

Figure 4. Balloon (float altitude) and parachute-borne blunt probe electrical conductivity measurements.

Below 40 km, there is no distinguishable difference between the positive and negative electrical conductivity values at a given altitude. The altitude dependence for electrical conductivity in the 20 to 40 km altitude region is approximately inversely proportional to that for neutral number density, thus suggesting that the dominant loss process for positive and negative ions is three-body ion-ion recombination. At 28 km, which is the STRATCOM V balloon's float altitude, the parachute-borne blunt probe measured an electrical conductivity value of 4.5×10^{-14} mho/cm.

STRATCOM V Balloon Flight

The blunt probe flown on the STRATCOM V balloon experiment was launched on 22 May 1974 at 0122 MST. The probe configuration was the same as that shown in Fig. 2 for the STRATCOM VI instrument package. A graph of the electrical conductivity data measured by this blunt probe is given in Fig. 5. The plus signs represent positive electrical conductivity measurements; the minus signs represent negative electrical conductivity values; and the dots represent those measurements for which there was no distinguishable difference in value between positive and negative electrical conductivity. Float altitude for the balloon package was approximately 28 km, as can be seen from the upper curve which is a plot of altitude versus local time. The solid lines below this curve connected time-averaged values of the positive and negative electrical conductivity data when the lamp was off.

The electrical conductivity measurements at float altitude when the lamp was off were typically in the range of 3 to 4×10^{-14} mho/cm. At 1132 MST (the time when the parachute-borne blunt probe was also at 28 km), a representative value for electrical conductivity was 3.5×10^{-14} mho/cm, which was within 25% of the value measured by the parachute-borne blunt probe.

In general, the electrical conductivity measurements above 5×10^{-14} mho/cm correspond to those times when the krypton discharge ionization lamp was on. If one assumes that the enhancements in positive electrical conductivity caused by the ionization lamp are predominantly associated with the photoionization of nitric oxide [4] and that a flow velocity of 2 m/s is representative of the balloon's vertical motion, an order of magnitude calculation for the nitric oxide concentration will yield a value of 10^{10} cm^{-3}. This value is very tentative; however, it is felt that the results demonstrate that the experiment is feasible at this altitude from a measurement sensitivity standpoint.

The decrease in electrical conductivity beginning at approximately 1400 MST corresponds to the time when the balloon was descending. The altitude dependence of electrical conductivity during descent was in good agreement with the corresponding data obtained by the parachute-borne blunt probe.

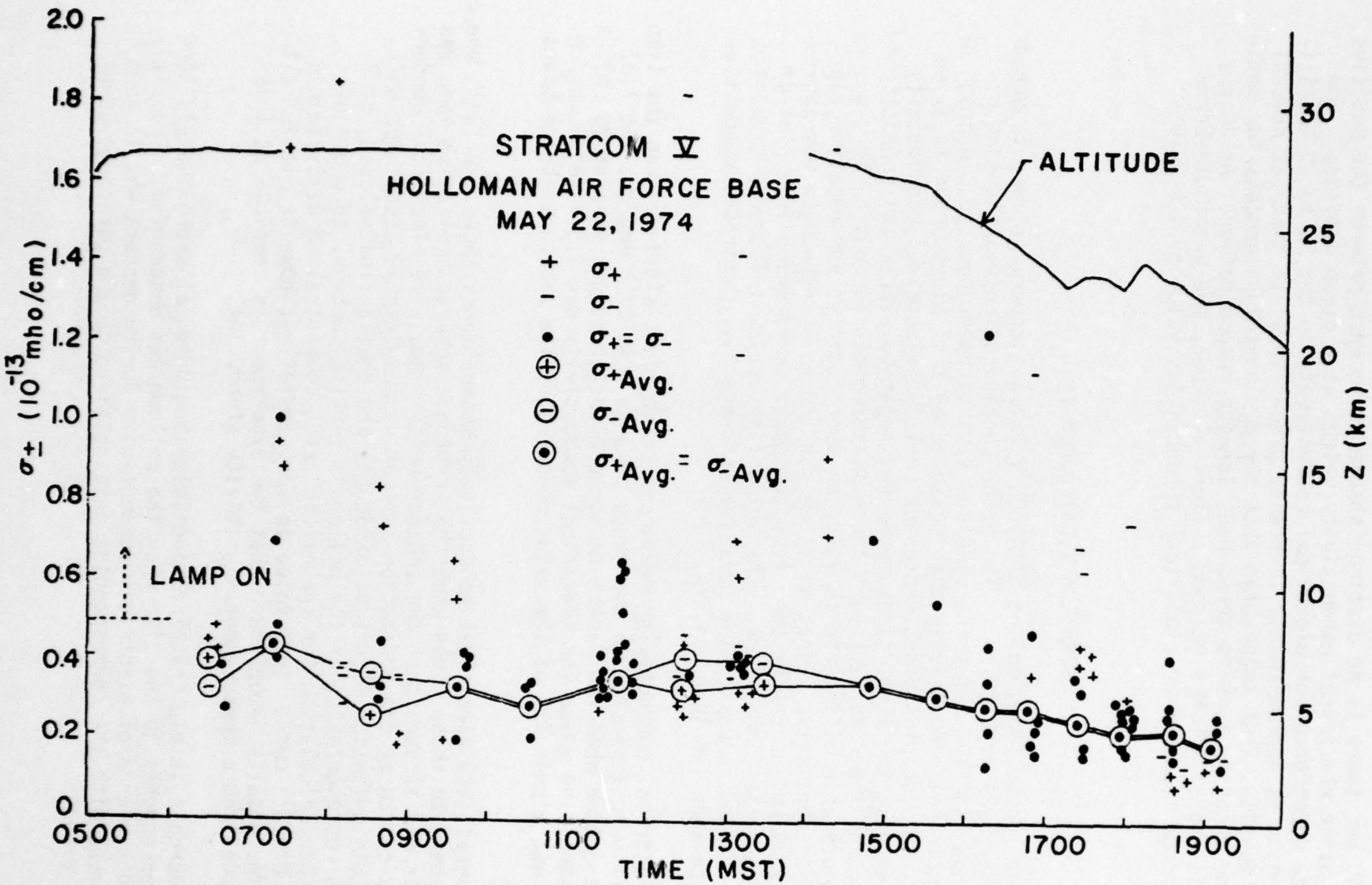

Figure 5. STRATCOM V electrical conductivity data.

STRATCOM VI Balloon Flight

The electrical conductivity measurements for the STRATCOM VI balloon experiment are shown in Fig. 6. The lower two curves on the graph represent time-averaged values for electrical conductivity measured by the blunt probe when the krypton discharge lamp was off. The upper curve shows the balloon's altitude as a function of time.

The balloon was launched at 2257 MST on 23 September 1975. The first conductivity measurements were obtained at 2345 MST ($Z \approx 11$ km), at which time the value for electrical conductivity was approximately 0.8×10^{-14} mho/cm. The negative electrical conductivity values for the balloon flight were generally larger than the corresponding positive electrical conductivity measurements, thus suggesting that the negative ions were comparatively more mobile than the positive ions. This was particularly evident during the ascent and float phases of the flight where the negative-to-positive electrical conductivity ratio was typically a factor of two.

The positive electrical conductivity values while the balloon was at float altitude ($Z \approx 39$ km) showed less variability than the negative electrical conductivity values and were typically in the range of 2 to 4 $\times 10^{-13}$ mho/cm. These positive conductivity values are representative of daytime rocket-launched parachute-borne blunt probe data (Fig. 4). The agreement between the float altitude positive conductivity data and the corresponding parachute-borne blunt probe measurements was generally better for the probe configuration used on the latter two STRATCOM balloon flights.

In conjunction with the blunt probe experiment, a krypton discharge ionization lamp was cycled on and off during designated periods of the flight. Enhancements in positive electrical conductivity of typically a factor of two to three were observed when the lamp was on. (These data are not shown in the figure.) The corresponding increases in negative electrical conductivity were considerably larger. The larger negative electrical conductivity values when the lamp was on suggest that possibly some free electrons were created by the lamp.

The balloon first began to descend at approximately 1000 MST on 24 September. During the descent, the electrical conductivity measurements decreased in value, with the decrease for negative electrical conductivity being significantly more noticeable. From approximately 1500 to 1900 MST while the balloon was still slowly descending, the values for the negative-to-positive electrical conductivity ratio ranged from 1.3 to 1.5, which are in general agreement with the negative-to-positive ion mobility ratio for light ions. After 2000 MST the balloon began to ascend, and again the curves for negative and positive electrical conductivity started to increase and diverge. This divergence in the two conductivity curves was characteristic of the ascent and float phases of the flight and continued until the scientific package was cut down at approximately 0900 MST on 25 September.

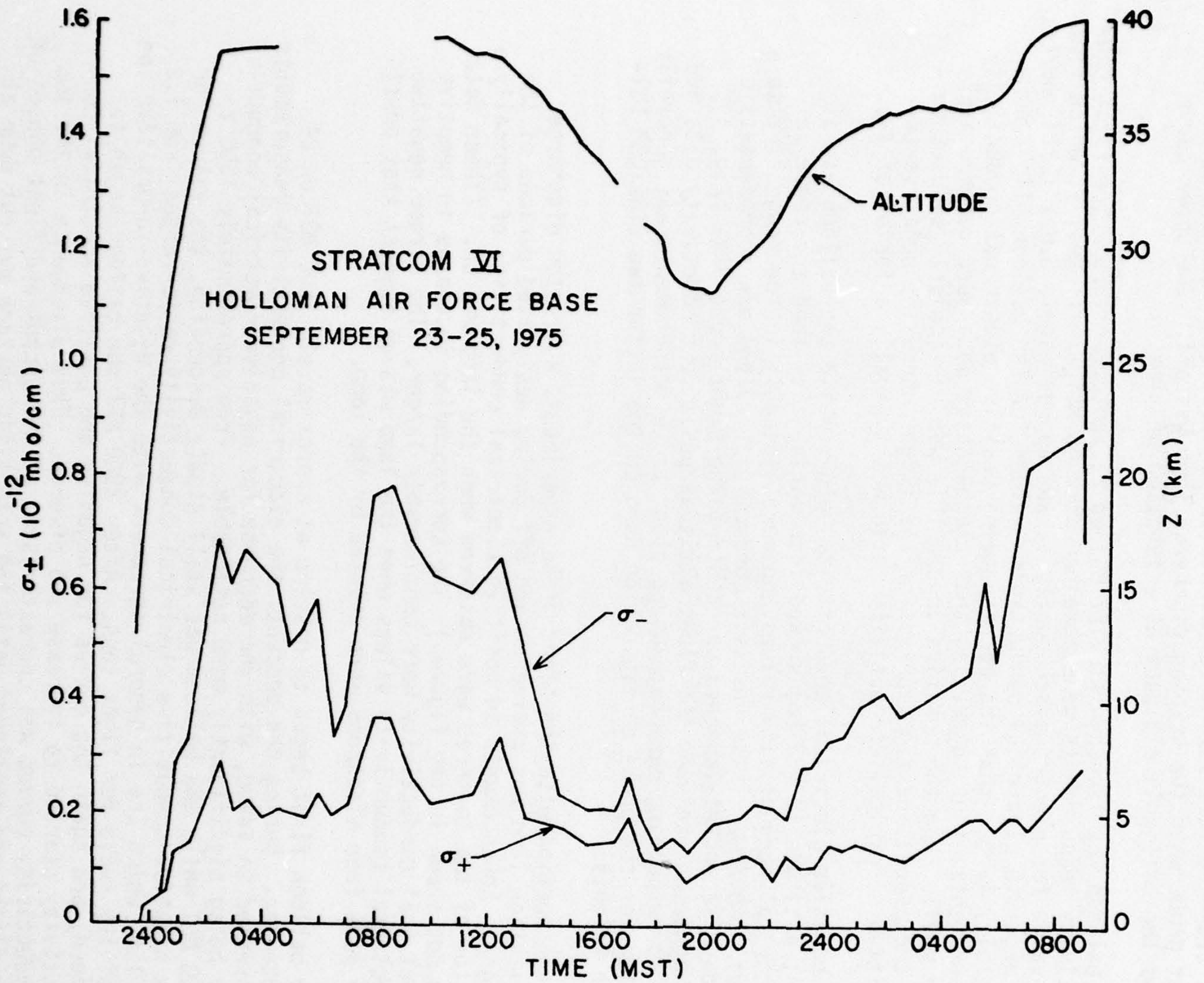

Figure 6. STRATCOM VI electrical conductivity data.

DISCUSSION

Blunt probe measurements obtained on balloon platforms are particularly useful for studying variations in electrical conductivity. Specifically, temperature variations, sunrise variations, and the altitude dependence of electrical conductivity will now be considered.

Previous studies using midlatitude, daytime positive electrical conductivity and temperature data from rocket experiments have shown a strong correlation between these two parameters [5]. This is particularly true in the 48 to 58 km altitude region where the temperature coefficient for positive conductivity is typically 4%/°K.

In studying the variability associated with the balloon positive conductivity measurements at float altitude, it is also helpful to consider the corresponding balloon air temperature measurements. Time-averaged values of positive conductivity versus air temperature at float altitude are plotted for the STRATCOM III data in Fig. 7. Only conductivity measurements attributable to background ions, i.e., those not associated with ionization caused by the Lyman-α lamp, were considered in this graph. The temperature coefficient deduced from a straight line fit to the data points is nominally 25%/°K, which is approximately six times the value previously determined from the parachute-borne blunt probe data for this altitude [5]. The strong temperature dependence for positive conductivity is thought to be at least partly a mobility effect in which temperature is influencing the degree of clustering of the hydrated positive ions. If in fact the ions collected by the balloon instrument are larger hydrated ions attributed to water outgassed from the balloon package, the corresponding higher temperature coefficient would suggest that the rate of clustering for the larger hydrates is more temperature dependent.

For the STRATCOM V positive conductivity data at float altitude ($Z \approx 28$ km), the conductivity variations were also observed to correspond to changes in atmospheric temperature. The temperature coefficient for the balloon conductivity data at this altitude, however, was typically 2%/°K. This lower value is comparable to the temperature coefficient deduced from the daytime parachute-borne blunt probe data for the altitude region [5] and would indicate that positive conductivity is a considerably less temperature dependent parameter at this lower altitude.

A progressive buildup in positive ion conductivity in the stratosphere during sunrise has recently been observed in parachute-borne Gerdien condenser and blunt probe data obtained at WSMR, NM, [6]. Enhancements in conductivity were measured down to 30 km, but were most noticeable between 45 and 50 km where an overall buildup on an order of magnitude was observed for a change in solar zenith angle from 90° to 53°. These conductivity enhancements are thought to be primarily associated with increases in positive ion mobility, possibly resulting from the photodissociation of larger positive ions into smaller, more mobile ions.

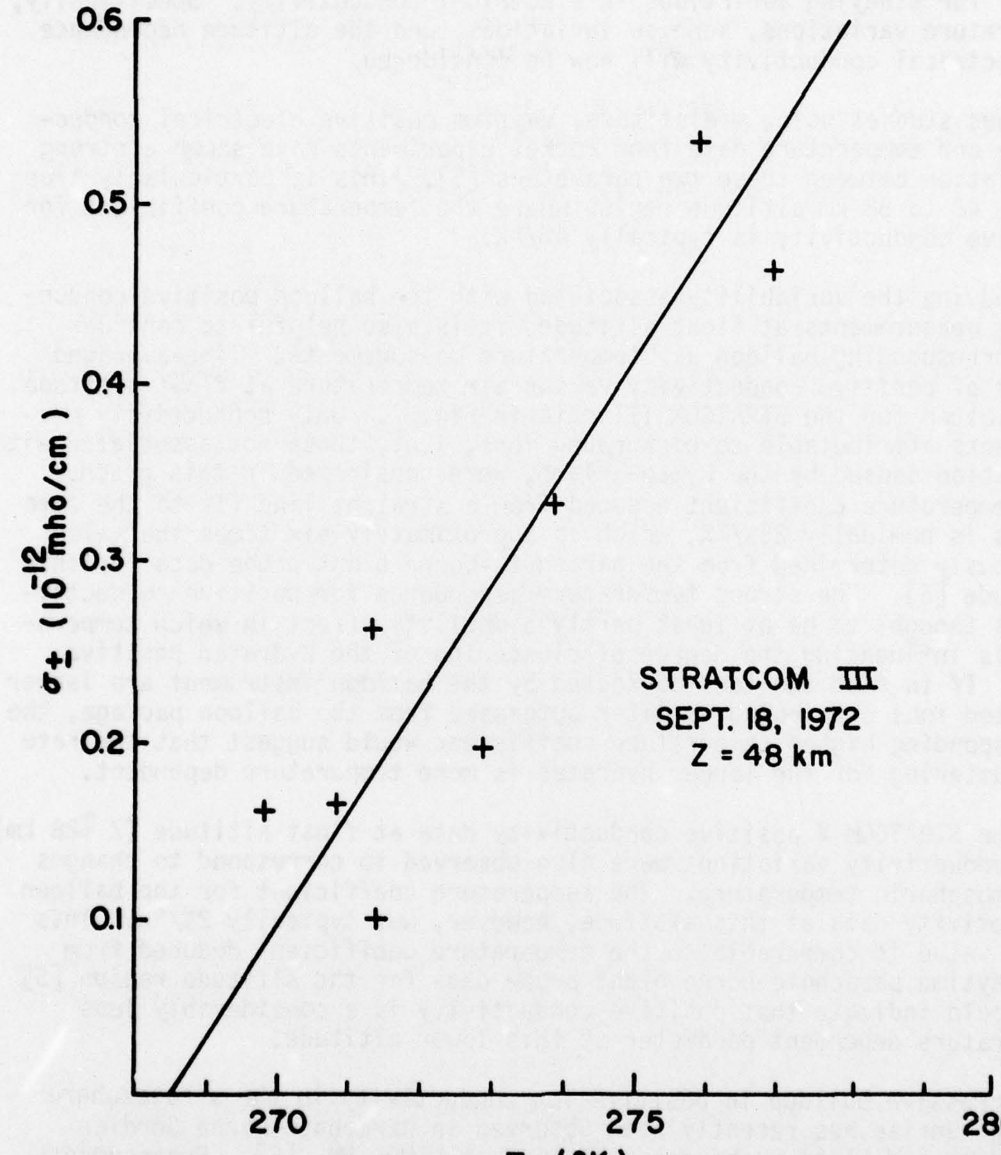

Figure 7. STRATCOM III positive electrical conductivity (float altitude, time-averaged) versus temperature.

Since the blunt probe's collector for the STRATCOM III flight was not directed vertically downward, solar-induced photoemission during sunrise caused the instrument to briefly shift in potential resulting in the data going off scale. For the STRATCOM V and STRATCOM VI flights, the downward-oriented probe had a sun shield over the collector and therefore sunrise data were obtained. Enhancements in both positive and negative electrical conductivity were observed in the float altitude sunrise data for the STRATCOM VI balloon flight. For the STRATCOM V conductivity data, no appreciable increase in value was observed at sunrise, thus indicating that the sunrise effects did not persist down to this lower float altitude.

The altitude dependence for electrical conductivity in the stratosphere is probably best demonstrated for all three STRATCOM flights by the data obtained after cutdown. For all three of these flights, the electrical conductivity measurements were observed to fall off in value after the scientific package was cut down and was descending on a parachute. The measurements after cutdown for the STRATCOM VI experiment are represented by the dots in Fig. 8. The curve in this figure is part of the parachute-borne blunt probe conductivity profile shown in Fig. 4.

Electrical conductivity data on the STRATCOM VI experiment were obtained from 37 km down to 17 km, with a value of approximately 2×10^{-14} mho/cm measured at the tropopause. No distinguishable differences were observed between the corresponding values for negative and positive electrical conductivity. The altitude dependence for the data in this region is inversely proportional to that for neutral number density. This is consistent with previously obtained parachute-borne blunt probe conductivity data, as demonstrated in Fig. 8. This form of altitude dependence is indicative of the lower stratosphere in which the loss process for positive and negative ions is predominantly three-body ion-ion recombination.

CONCLUSIONS

In summary, blunt probe conductivity experiments have been flown on the recent series of STRATCOM balloon flights launched from HAFB, NM, to study ionization processes in the stratosphere. These experiments were found to be particularly useful for studying conductivity variations associated with temperature, sunrise conditions, and altitude.

The float altitude conductivity measurements were in general agreement with previously obtained rocket-launched parachute-borne blunt probe data, particularly for the STRATCOM V and STRATCOM VI flights where the blunt probe was extended horizontally on an arm from the rest of the scientific package.

During certain periods of the flights, an ultraviolet lamp was operated in conjunction with the blunt probe experiment in a configuration such that the probe was used to study the lamp's ionization effects on the

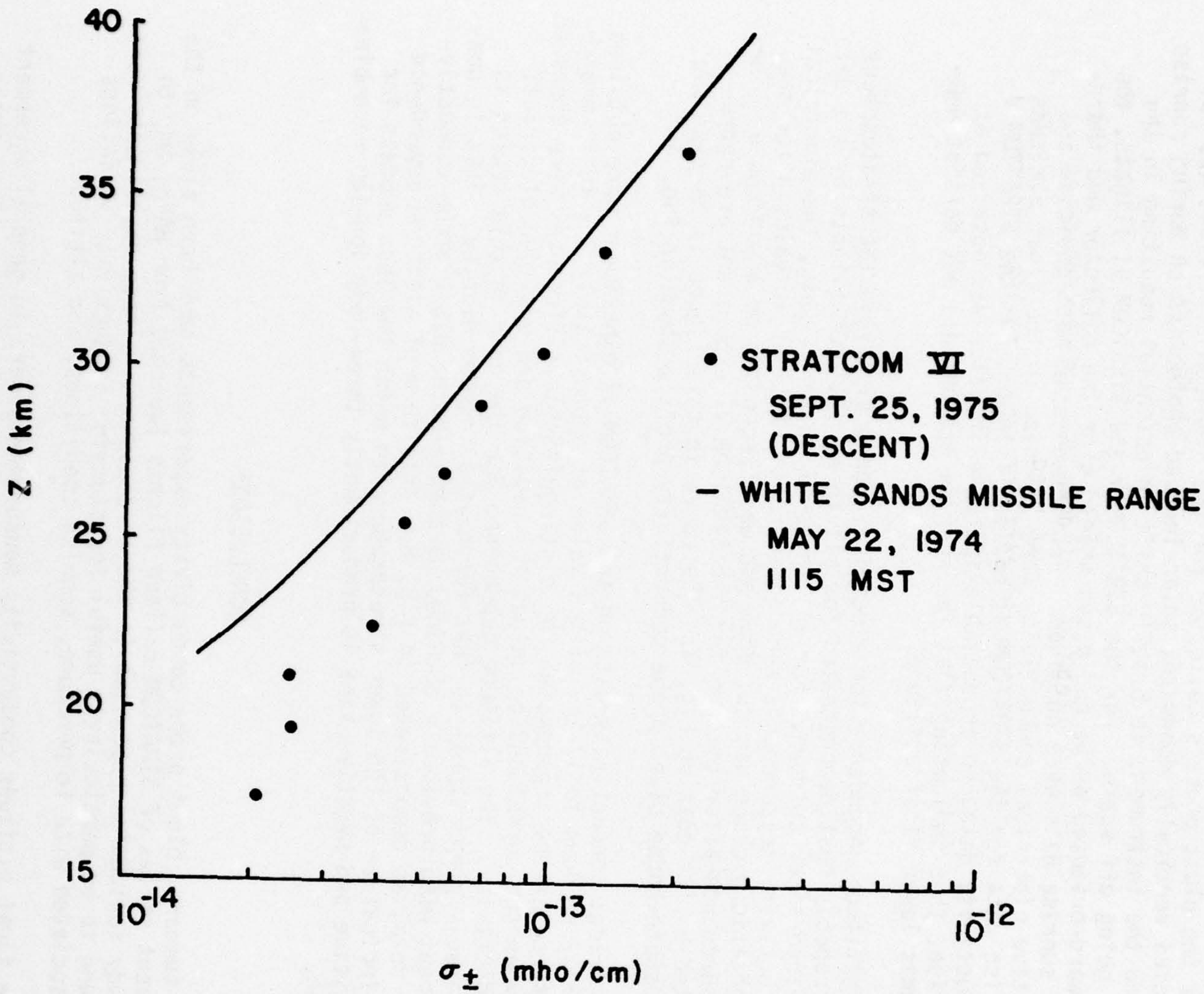

Figure 8. STRATCOM VI descent and parachute-borne blunt probe electrical conductivity measurements.

stratosphere. Appreciable enhancements in both positive and negative electrical conductivity were observed on all three flights when the lamp was on.

After the scientific package was cut down and was descending on a parachute, the blunt probe experiment was used to obtain an altitude profile for electrical conductivity. The altitude dependence for electrical conductivity was observed to be in good agreement with measurements from previously obtained rocket-launched parachute-borne blunt probe experiments.

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